THE DAWN OF THE SUPERSONIC AGE

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It is a great honor and pleasure to be invited to give one of the public lectures in your engineering lecture series. This lecture will not be a technical paper in the usual sense and has none of the usual appurtenances of such papers. It is in part an attempt to interpret the aims, goals, and effects in human affairs of one field of development in aeronautical engineering; in part an attempt to give you a nodding acquaintance with some of the current technical problems in that field.

Last week while I was standing with a group of aeronautical engineers on the lawn of the Inn at Williamsburg, Virginia, there was heard that new and never-to-be-forgotten sound, the high pitched swish of a jet-propelled aircraft somewhere in the sky. Everyone began to use their natural sound locators, turning the head back and forth to obtain equal intensity of sound in the two ears and looking straight ahead to locate the source, but no airplane was to be seen. Then a wiser and more experienced operator called out "You have to look ahead of the sound" and sure enough by looking a considerable distance ahead of the apparent origin of the sound, the airplane was readily located. The jet airplane travels at such a large fraction of the speed of sound that in the time required for the sound to travel the distance from the airplane to the observer, the airplane has moved a comparable distance along its path.

In London during the last war the inhabitants were harassed by two types of distinctive missiles. The buzz-bomb traveling much slower than the speed of sound telegraphed its coming long in advance, holding its victims in terrifying suspense. The V-2 rocket traveling several times faster than sound was more merciful. No warning sound was propagated and the victims never knew what happened. The survivors saw the explosion and only afterward heard the noise arising at successive points along the path in reverse order, much like a phonograph record played backwards.

These human experiences have brought into our daily speech a familiarity with the use of the speed of sound as a measure of comparison for the speeds of aircraft and missiles and with the new words coined by scientists, sonic speed for a speed equal to that of sound; subsonic speed for speeds less than that of sound; supersonic speed for speeds greater than that of sound; transonic speed for speeds just below and above the speed of sound especially for objects which pass <u>through</u> the speed of sound in their travel; and Mach number, the ratio of the speed of the aircraft or missile to the speed of sound.

The scientist uses the sonic speed as his measure not because of the difference in travel of sound to an observer, previously described, but because he finds by experiment that the laws of air flow are greatly different for subsonic and supersonic speeds. George W. Gray, in his book on Frontiers of

Flight, which is a history of the wartime work of the National Advisory Committee for Aeronautics, recounts the story of an American fighter pilot during the last war who dove his airplane steeply toward the earth in pursuit of a German fighter plane. After shooting down the German plane, he attempted to pull back on the control stick to level out from the dive. But the stick resisted and seemed held in a vice. With all his strength he struggled, but the airplane continued downward at high speed. As he was ready to abandon ship the elevator suddenly took hold and the plane curved out of the dive with high acceleration. This new and baffling experience arose from the fact that the speed of the airplane was reaching a speed at which the air was flowing locally over parts of the wings and tail at speeds faster than sound although the airplane itself was traveling at only three-quarters the speed of sound.

Why did the airplane recover at all? The explanation is that the speed of sound changes as the temperature of the air changes. Near the ground in the warm air at sea level it is about 760 miles per hour. In the upper atmosphere where the temperature is about -55° F. the speed of sound is only 660 miles per hour. Thus as the airplane dived, its speed, decreasing slowly because of the increasing density of the air, became smaller in comparison with the speed of sound and the adverse effects disappeared.

The great task confronting the NACA, university, industrial, and other government research laboratories is the prompt exploration of the laws of airflow in the transonic and supersonic regions. The task of the designers of military aircraft is to apply this knowledge to build aircraft which may fly safely at these speeds. Many existing aircraft can enter the transonic region, at least in dives. For security reasons I do not expect to tell you exactly the limits of speed which have been reached under various conditions. I can state that we are at the dawn of the supersonic age in the sense that many aircraft now flying,travel at such high speeds that the air flows locally past their wings at speeds faster than sound and that it is only a matter of time before sustained horizontal supersonic flight of piloted aircraft will be a commonplace event, as the dawn is superseded by the full sunlight of the oncoming day. I am on record as having predicted last fall that the sunrise of the new age will occur before the end of the calendar year 1948. Some newspaper men say it has already occurred. In the present international climate I predict a cloudy sunrise and there will be some difficulty in determining exactly when the dawn turns to day.

The impact of engineering development in aeronautics on our civilization has from the beginning been very great. Airplanes of ever increasing performance have served our civilization usefully. At first flying was the hazardous occupation of a few men who capitalized on the danger to entertain and to thrill the many by aerial circuses and races. Some more far-seeing pilots began to demonstrate the peacetime utility by pioneering in aerial photography, crop dusting, the carrying of mail, passengers, and freight. These peacetime useful services of aviation have grown to large size and aircraft are indispensable to our economy. It is possible to do things which were impossible before; for example, I could leave Washington Sunday afternoon, speak in Berkeley on Monday evening, Los Angeles Tuesday evening, and be back in Washington on Wednesday evening.

You will recall the introduction of the airplane as a military weapon in World War I and its rapid development to become today the Keystone of our national security. It is the pressing claim of this use of the airplane that has brought the dawn of the supersonic age as we shall later discuss.

These are the direct contributions to the machinery of daily living and fighting. But the indirect contributions to man's intellectual and spiritual life are even more striking. Aeronautical developments have endless ramifications in the daily lives and mental processes of all of us, engineers, educators, business men, John Q. Public, or however else we may wish to classify ourselves or our major interests. Aeronautical engineering has left its impress on other branches of engineering as well as on society as a whole. In these times we cannot afford as engineers to ignore this consequence of our work and in this discussion I do not propose to ignore the human aspects of our technical work.

I may illustrate the way in which a complex technical development can affect the life of the average man by reviewing very briefly an earlier age of aeronautical development, the streamline age. You probably recall the early airplane, usually a wood, wire, and fabric creation with exposed struts, wires, engine, landing gear, and passengers. You probably remember the development of the cantilever monoplane, of the cowling of the aircooled engines, of the retractable landing gear, all greatly reducing the drag and increasing the speed. Perhaps you have seen the flow of smoke or water around objects of various shapes and are familiar with the concept of a streamline body as a body which moves through the air or water leaving behind it the least possible disturbance. You know that your automobile or a train is not really a good streamline body because of the cloud of dust and debris stirred up by its passage. Although the development of streamlined aircraft has been carried to a high point even to the removal of rivet heads on the exterior surface, and the principle has been in part applied to automobiles and trains, surely the more important influence has been on the intellectual and spiritual lives of men. And by that I do not refer particularly to the rather facetious and frivolous application of the adjective "streamline" in advertising to furnaces, washing machines, flat irons, women's stockings, men's shirts, and the female figure, but to the more solid and meaningful concept of that harmony with the physical laws of the universe which enables us to live with a minimum of useless effort and disturbance. The streamlining of office procedures, of the Committees of Congress, of specifications for materials, of college curricula; -- all such concepts grew out of this impact of the aeronautical engineering development of an aircraft which traveled through the air with a minimum of disturbance, with each part functional and operating at peak efficiency. I have heard also in government bureaus of streamlining the buck so that it may more readily be passed from one office to another. But surely more important than all of these is the streamlining of one's life so that we may proceed with a minimum of friction with our neighbors, with our energies applied to the task of reaching our goals swiftly.

In similar fashion I assert that the supersonic age will profoundly affect the lives of all of you, physically, mentally, and spiritually and hence you should become familiar at this early date with this oncoming technical development.

Let us look at some of the technical problems to be solved in the development of supersonic piloted aircraft. In general terms the problems arise from the radical changes in the aerodynamic relationships at speeds faster than sound as compared with those prevailing at speeds slower than sound. A reasonably satisfactory design could now be made to operate at any one value of the speed, subsonic or supersonic, if the transonic region of mixed flow is avoided. However, any practical airplane must be able to take off and land and hence must be able to fly satisfactorily in both the subsonic and supersonic regimes and also during the passage through the transonic region. In fact, it would be desirable to be able to fly steadily in the transonic region as well.

The first problem is that of providing a powerplant of sufficiently high thrust to overcome the drag or resistance to motion at supersonic speeds. Ballisticians many years ago found that the resistance to motion of a projectile increased disproportionately as the speed of sound was approached, the drag increasing much faster than the square of the speed. About 20 years ago experiments in which I had some part showed that the drag coefficient of an airplane wing increased suddenly many fold and the lift coefficient decreased very greatly in the transonic region. These findings have repeatedly been confirmed. The development of jet and rocket propulsion has now given us powerplants of large thrust in a relatively small package. There are three types of jet powerplants available or under development; the turbo-jet, the ram-jet, and the rocket, each producing thrust as the result of squirting a hot jet of air to the rear. Any boy who has blown up a toy balloon and let it escape from his hands has observed jet propulsion and therefore can understand it. As a matter of fact, the conventional airplane propeller operates by producing a jet. In the newer engines heat is used to produce the jet. The rocket carries both fuel and oxygen, i.e., all the elements required for a chemical reaction to produce heat, transform the fuel and oxidant to hot gas, and eject the products of combustion. It therefore can operate anywhere, under water, in the air or outside the earth's atmosphere.

Turbo-jet and ram-jet engines get their oxygen from the atmosphere, as does the conventional reciprocating engine. The turbo-jet uses a mechanical compressor to compress the air and a turbine to drive the compressor. In the ram-jet compression is produced by the rapid motion of the vehicle; hence a ram-jet propelled vehicle must be brought to a high speed by other means, for example, booster rockets.

The new powerplants give a great deal of power per pound of weight and have the desirable characteristic that the power increases with the speed. In his book Gray gives the following figures at a speed of 750 miles per hour for certain powerplants: Rocket 53.7 horsepower per pound; ram-jet 6.9 horsepower per pound; turbo-jet 3.5 horsepower per pound. However, at the same speed the rocket burns 8.3 pounds of fuel per horsepower hour; the ram-jet 2.8; the turbo-jet 1.0. The relative merits of the engine types are complicated functions of the speed and altitude of flight. Suffice it to say that these powerplants furnish sufficient power to drive aircraft at supersonic speeds. Much research is required to improve their efficiency, reliability, and limits of operation as regards speed and altitude.

The converse of the problem of producing sufficient thrust is reduction of drag. Here again considerable progress has been made. The introduction of sweptback wings heralds the new-look for high-speed aircraft, although all airplanes having sweepback do not necessarily travel at supersonic speeds. Sweepback is highly advantageous in the transonic region. At supersonic speeds model tests indicate advantages for a triangular planform or short stubby thin wings.

The drag can be greatly reduced by reducing the density of the air by traveling at high altitude, but as is well known, high altitude flight introduces new problems both for the human occupant and the powerplant. As the density is reduced, a greater and greater volume of air must be forced through the engine to supply the necessary oxygen to burn the fuel in the case of the ram-jet and turbo-jet. It becomes more and more difficult to maintain the conditions needed for combustion, to "keep the fire lit" in the parlance of the jet pilot. Research workers are busily engaged on these questions. It is obvious that supersonic flight near the ground will be extremely costly in fuel, and that economy and efficiency ~~is~~ are to be obtained by high altitude flight. Hence the interest today in determining the physical properties of the air at very high altitudes by means of sounding rockets, and in reproducing these conditions in the laboratory for studying the problems to be encountered in high-speed flight in the upper atmosphere. Professor Folsom and his associates here at the University of California are doing pioneering work in this field.

Perhaps the most difficult technical problems are those relating to control and stability. At subsonic speeds the lifting force on a wing acts through a point about one-quarter the distance from the leading edge to the trailing edge; at supersonic speeds it acts through a point half the distance from leading to trailing edge. Thus there are sudden changes in the trim of the airplane in the transonic region. There are also changes in the stability, produced partly by the change in the airflow at the tail produced by the loss of lift. A number one research problem is to find configurations which go through the transonic region with minimum changes in trim, control, and stability.

Research has shown that disturbances known as shock waves develop in the flow near the wing at transonic speeds and that these shock waves are often accompanied by flow separation. When this occurs the air flows past the wing with violent fluctuations shaking or buffeting the wing and if the wing wake strikes the tail, the tail structure may be subjected to violent irregularly varying loads sufficient to produce structural damage. A knowledge of buffeting loads and, if possible, the design of wing sections and configurations which avoid flow separation are necessary to develop aircraft to fly safely in the transonic region.

The configurations which seem best for flight at supersonic speeds usually show poor landing characteristics. Much research is needed on methods for improving these characteristics by use of suitable flaps or by methods as yet unknown.

At high speeds the loads on the wings and tail are large and produce deflections, twisting, and bending of the structure. These distortions change the air loads and there is thus a complicated interaction between aerodynamic and structural design. For example, the deflection of the aileron to correct a disturbance in roll may twist the wing enough to counteract the desired effect of the aileron, thus increasing the disturbance. Difficult aeroelastic problems must be solved by the designer.

It is well known that meteors traveling through the air at high supersonic speeds get so hot from friction with the air that their surface melts. At lower supersonic speeds the heating is by no means negligible and is already receiving consideration even at subsonic speeds. In a piloted aircraft the cabin or cockpit must be kept at a reasonable temperature say less than 100° F. Refrigeration is required at speeds as low as 500 miles per hour, partly because of aerodynamic heating, but partly because of radiation from the sun. In a pilotless aircraft or missile the temperature could be permitted to go somewhat higher but ultimately a point is reached at which mechanical and electrical devices will not function or the structural properties of the materials are greatly deteriorated by the high temperature. Whether or not a piloted supersonic airplane can be flown at high supersonic speeds may be determined by the results of research on methods of cooling the cabin and the structure.

These technical problems are being attacked by many new and ingenious tools, the best known being the wind tunnel. The first supersonic experiments with which I am familiar were made in 1890 in a jet about a quarter of an inch in diameter, the flow lasting about three seconds. Now there are supersonic wind tunnels 1 foot by 3 feet in cross section in regular operation and others 6 feet by 6 feet and 6 feet by 8 feet approaching completion. Techniques for measurements on objects dropped from aircraft at high altitudes and on rockets fired from the ground at supersonic speeds have yielded much valuable information. Still another method is to place a model in the local region of supersonic flow on the upper surface of the wing of an airplane traveling at high subsonic speeds, a method devised by Mr. Gilruth of the NACA. The same technique was applied by Lockheed and by the NACA by installing a bump in a subsonic wind tunnel.

So much for the purely technical aspects. Why does anyone wish to travel faster than sound? Dr. von Karman once closed a technical lecture with this question and stated that the reply must be left to the philosopher, but all of us must be, to some extent, philosophers, if amateur ones. There is no question but that the primary motive of our nation in devoting large sums of money and time to accomplish supersonic flight is the desire for national security. The dominant position of air power as an element in national security has been thoroughly demonstrated. Speed has always been that element of performance of an aircraft which makes it possible to control the air. We have been told by our military leaders that had Hitler grasped the significance of the development of turbo-jet and rocket-propelled aircraft and exploited them, our bomber missions could not have continued as then operated over Germany. All of us observed the inability of England to defend itself against supersonic V-2 missiles, once the missiles were launched. Speed is the major characteristic of the fighter and intercepter and speed is the most important defensive armament of the bomber. There now seems to be no technical obstacle which cannot be overcome by research and the fear that some other nation may produce faster aircraft which could outrun our own aircraft in the sky is the powerful incentive to desire to travel faster than sound.

Finally as to why fly faster than sound, I will not have you discount the value of speed in commercial air transport when accompanied by safety and reliability. It now takes about twelve hours elapsed time to cross the continent, and the trip is very comfortable in modern aircraft. Nevertheless, it would be still more comfortable if it could be done in three cr four hours. It is easy to predict that this will surely come; it is harder to predict the timing. Over the years the speed of commercial air transport operation has lagged the airplane speed record by 15 or 20 years. Hence we might estimate that in 1968 the speed of commercial air transports would be about 650 mph, the present speed record. But the jet engine has introduced a discontinuity, the possibility of a sharp rise in the rate of development, and hence this performance may come earlier. There are many optimists who day dream about aeronautical progress without adequate technical support for their predictions and there are also more sober and solidly-based predictions. The conservative predictions have usually been outstripped. As recently as 1940 Archibald Black, an aviation writer, made the following statement: "It has been estimated that if it were possible to build an airplane that could fly at more than 800 miles per hour, the rocket principle might then be promising. This speed, however, is yet too fantastic to be considered even as a future possibility, although it is always dangerous to say of anything in aviation that 'it will never come'." This speed does not now seem so far away. Research today on speeds faster than sound is research on the commercial air transport of the future.

The achievements of aeronautical engineering have had a stimulating effect on other branches of engineering. The supersonic age will influence the training of all engineers as well as contribute to developments in mechanical and electrical engineering. Solution of the manifold problems of supersonic flight requires both an increasing specialization of individual engineers and improved methods of synthesizing the efforts of specialists toward a common goal. There is need for men who have detailed mastery in such diverse fields as organic chemistry (for fuels for turbo-jets, ram-jets, and rockets), metallurgy, ceramics (for heat-resistant materials), dynamics of structures (vibration and flutter problems), electronics (for instruments and control devices), servomechanisms (for autopilots, gunsights, and gunlaying), aerodynamics, thermodynamics, and many others. There must be experts in the borderline fields, such as aeroelastic problems, aerothermodynamics, etc. Each of these is a field in which the body of knowledge and experience is steadily growing and each requires the full time energy of anyone for its mastery.

The work of specialists must be integrated to an extent not required in other branches of engineering. Engineers in other fields have successfully met the problems of large enterprises, planning the flow of materials, arranging for matching of characteristics of components, securing dimensional agreement of mating parts. In most of these fields the problems can be broken down readily for solution, with the coordination requiring only small adjustments. In a supersonic aircraft or missile, each special problem reacts on all the others to an extent demanding a new type and higher order of coordination. For example, such an apparently simple thing as the design of a radar antenna cannot be adequately treated without consideration of the effects on the aerodynamic characteristics and hence on the required powerplant. A suitable compromise must be worked out between many conflicting requirements. A group of leaders must be trained who can intelligently make these compromises. They must be men with broad training in many fields with mastery of mathematical and experimental methods of analysis of complex problems, and with a certain boldness of venture.

Aeronautical engineers engaged in work on guided missiles have learned the great stimulus of boldly attempting to design an operating missile. Granting that all the desired basic research has not been completed, the attempt to sink or swim in the venture reveals what the key problems really are and in conjunction with rational mathematical analysis enables the development effort to be concentrated on the real obstacles to progress. Engineers must be taught to use the coordinated experimental and theoretical attack on their problems to utilizing the skills of specialists, and to weigh, balance, and evaluate the data obtained from all. Such is the mode of operation of the engineer in a supersonic age.

The supersonic age will also make its imprint on the average man. As in the case of the atomic bomb, the supersonic age will at first bring fear to his mind because of its portent for war. Engineers are prone to direct attention to the material benefits of their creations to the public, to the power of many slaves which they have supplied to do physical labor, to their contributions to ease and comfort, and they are equally prone to ignore the common belief that scientific and technical developments appear often to bring misfortune. The truth, of course, is that material things are neither good nor evil; they may be used for either purpose by good or evil men. The same chemical compound brings you the blessing of clean white shirts and the curse of a poisonous gas to be used in war. Another gives you broad, paved streets, mines your coal, or crumbles buildings and cities. The supersonic age likewise is in itself neither a blessing nor a curse. It may be either.

The faster transport of the supersonic age will dissolve barriers of time and space and the world will shrink still more, increasing the pressure for solution of many social, political, and economic problems. When man can outrun the sun and arrive at his destination before he leaves, as measured by the sun, he must obtain a new perspective of international and sectional problems.

The supersonic age will bring a lifting of intellectual horizons as having conquered the space and time limitations of this world, he ? seeks new worlds to conquer. He ? will begin to think more seriously about the exploration of the high upper atmosphere and to wonder whether the exploration of outer space is not more than a figment of the human imagination.

But man must not be too impatient. He has climbed far. The realization of his dreams requires the time and effort of many, perhaps even of generations. And you and I can only regret that we cannot linger to see of what stuff these dreams are made.